ANNEX O

Methodology for Estimating CH_4 Emissions from Landfills

Landfill methane (CH_4) is produced from a complex process of waste decomposition and subsequent fermentation under anaerobic conditions. The amount and rate of methane production depends upon the characteristics of the landfilled material and the surrounding environment. To estimate the amount of methane produced in a landfill in a given year, the following information is needed: the quantity of waste in the landfill, the landfill characteristics, the residence time of the waste in the landfill, and the landfill capacity.

The amount of methane emitted from a landfill is less than the amount generated. If no measures are taken to extract the methane, a portion of it will oxidize as it travels through the top layer of the landfill cover. The portion of the methane that oxidizes turns primarily to carbon dioxide (CO_2). If the methane is extracted and combusted (e.g., flared or used for energy), then that portion of the methane produced in the landfill will not be emitted as methane, but again, would be oxidized to CO_2. In general, landfill-related CO_2 emissions are of biogenic origin and primarily result from the decomposition, either aerobic or anaerobic, of organic matter such as food or yard wastes.[1]

Methane emissions are primarily driven by the quantity of waste in landfills. From an analysis of the population of municipal solid waste (MSW) landfills, landfill-specific data were extracted and used in an emissions model to estimate the amount of methane produced by municipal solid waste. Although not explicitly modeled, methane emissions from industrial landfills were assumed to be seven percent of the total methane generated from MSW at landfills. Total methane emissions were estimated by adding the methane from MSW landfills, subtracting the amount recovered or used for energy or flared, subtracting the amount oxidized in the soil, and adding emissions from industrial landfills. The steps taken to estimate emissions from U.S. landfills for the years 1990 through 2000 are discussed in greater detail below.

Step 1: Estimate Municipal Solid Waste-in-Place Contributing to Methane Emissions

First, landfills were characterized as of 1990 based on a landfill survey (EPA 1988). Each landfill was characterized in terms of its year of opening, waste acceptance during operation, year of closure, and design capacity. Following characterization of the landfill population, waste was simulated to be placed in these landfills. For 1990 through 2000, waste disposal estimates were based on annual *BioCycle* (2001) data. Landfills were simulated to open and close based on waste disposal rates. If landfills reached their design capacity, they were simulated to close. New landfills were simulated to open when a significant shortfall in disposal capacity was predicted. Simulated new landfills were assumed to be larger, on average, reflecting the trend toward fewer and more centralized facilities. The analysis updated the landfill characteristics each year, calculating the total waste-in-place and the profile of waste disposal over time. Table O-1 shows the amount of waste landfilled each year and the total estimated waste-in-place contributing to methane emissions.

Step 2: Estimate Landfill Methane Production

Emissions for each landfill were estimated by applying the emissions model (EPA 1993) to the landfill waste-in-place contributing to methane production. The model estimates that landfilled waste generates methane for 30 years after disposal. Total emissions were then calculated as the sum of emissions from all landfills, open and closed.

Step 3: Estimate Industrial Landfill Methane Production

Industrial landfills receive waste from factories, processing plants, and other manufacturing activities. Because no data were available on methane generation at industrial landfills, emissions from industrial landfills were assumed to equal seven percent of the total methane emitted from MSW landfills (EPA 1993). The EPA

[1] Emissions and sinks of biogenic carbon are accounted for in the Land-Use Change and Forestry chapter.

landfill survey contained estimates of industrial waste (EPA 1988). The organic content of industrial waste represents seven percent of the methane producing capacity of MSW. These emissions are shown in Table O-2.

Step 4: Estimate Methane Emissions Avoided

The estimate of methane emissions avoided was based on landfill-specific data on flares and landfill gas-to-energy (LFGTE) projects.

Step 4a: Estimate Methane Emissions Avoided through Flaring

The quantity of methane flared was based on data collected from flaring equipment vendors, including information on the quantity of flares, landfill gas flow rates, and year of installation. To avoid double counting, flares associated with landfills that had an LFGTE project were excluded from the flaring analysis. Total methane recovered was estimated by summing the median landfill gas flow rate for each remaining flare. However, several vendors provided information on the size of the flare rather than the landfill gas flow rate. To estimate a median flare rate for flares associated with these vendors, the size of the flare was matched with the size and corresponding flow rate provided by the other vendors.

Step 4b: Estimate Methane Emissions Avoided through Landfill gas-to-energy (LFGTE) projects

The quantity of methane avoided due to LFGTE systems was estimated based on information in a database compiled by EPA's Landfill Methane Outreach Program (LMOP). Using data on landfill gas flow and energy generation, the total direct methane emissions avoided were estimated.

To avoid double counting flares associated with LFGTE projects, the flare estimates were adjusted to account for LFGTE projects for which an associated flare could not be identified.

Step 5: Estimate Methane Oxidation

As discussed above, a portion of the methane escaping from a landfill through its cover oxidizes in the top layer of the soil. The amount of oxidation that occurs is uncertain and depends upon the characteristics of the soil and the environment. For purposes of this analysis, it was assumed that ten percent of the methane produced, minus the amount of gas recovered for flaring or LFGTE projects, was oxidized in the soil (Liptay et al. 1998).

Step 6: Estimate Total Methane Emissions

Total methane emissions were calculated by adding emissions from MSW and industrial waste, and subtracting methane recovered and oxidized, as shown in Table O-2.

Table O-1: Municipal Solid Waste (MSW) Contributing to Methane Emissions (Tg unless otherwise noted)

Description	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Total MSW Generated[a]	266	255	265	278	293	296	297	309	340	347	371
Percent of MSW Landfilled[a]	77%	76%	72%	71%	67%	63%	62%	61%	61%	60%	61%
Total MSW Landfilled	205	194	191	198	196	187	184	188	207	208	226
MSW Contributing to Emissions[b]	4,926	5,027	5,162	5,292	5,428	5,559	5,676	5,790	5,906	6,035	6,147

[a] Source: *BioCycle* (2001). The data, originally reported in short tons, are converted to metric tons.

[b] The emissions model (EPA 1993) defines all waste that has been in place for less than 30 years as contributing to methane emissions.

Table O-2: Methane Emissions from Landfills (Gg)

Activity	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
MSW Generation	**11,599**	**11,837**	**12,168**	**12,499**	**12,847**	**13,218**	**13,490**	**13,774**	**14,015**	**14,348**	**14,617**
Large Landfills	4,780	4,817	4,883	4,950	5,038	5,129	5,199	5,280	5,351	5,453	5,520
Medium Landfills	5,545	5,720	5,954	6,190	6,424	6,682	6,868	7,057	7,211	7,424	7,614
Small Landfills	1,273	1,300	1,332	1,359	1,385	1,407	1,423	1,438	1,453	1,471	1,483
Industrial Generation	**731**	**746**	**767**	**787**	**809**	**833**	**850**	**868**	**883**	**904**	**921**
Potential Emissions	**12,330**	**12,582**	**12,935**	**13,286**	**13,657**	**14,051**	**14,340**	**14,642**	**14,898**	**15,252**	**15,538**
Emissions Avoided	**(1,119)**	**(1,387)**	**(1,601)**	**(1,848)**	**(2,225)**	**(2,682)**	**(3,244)**	**(3,820)**	**(4,362)**	**(4,607)**	**(4,874)**
Landfill Gas-to-Energy	(692)	(728)	(784)	(855)	(977)	(1,017)	(1,171)	(1,415)	(1,729)	(1,984)	(2,196)
Flare	(427)	(659)	(817)	(994)	(1,248)	(1,665)	(2,073)	(2,405)	(2,633)	(2,623)	(2,678)
Oxidation	**(1,048)**	**(1,045)**	**(1,057)**	**(1,065)**	**(1,062)**	**(1,054)**	**(1,025)**	**(995)**	**(965)**	**(974)**	**(974)**
Net Emissions	**10,162**	**10,150**	**10,277**	**10,373**	**10,370**	**10,315**	**10,072**	**9,827**	**9,571**	**9,671**	**9,690**

Note: Totals may not sum due to independent rounding.

Note: MSW generation in Table O-2 represents emissions before oxidation. In other tables throughout the text, MSW generation estimates account for oxidation.